

Description

Comb filter arrangement for decimating a sequence of digital input values into a sequence of digital output values by a non-integral factor

The present invention relates to a comb filter arrangement for decimating a sequence of digital input values into a sequence of digital output values by a non-integral factor.

EP 0889587 A1 discloses such a comb filter arrangement which has an input-end integrator whose output is fed to two signal paths, each signal path having an adjustable delay stage and a following decimator stage as well as an output-end differentiator stage. In addition, in this known comb filter arrangement there is a buffer which carries out the function of an interpolation stage.

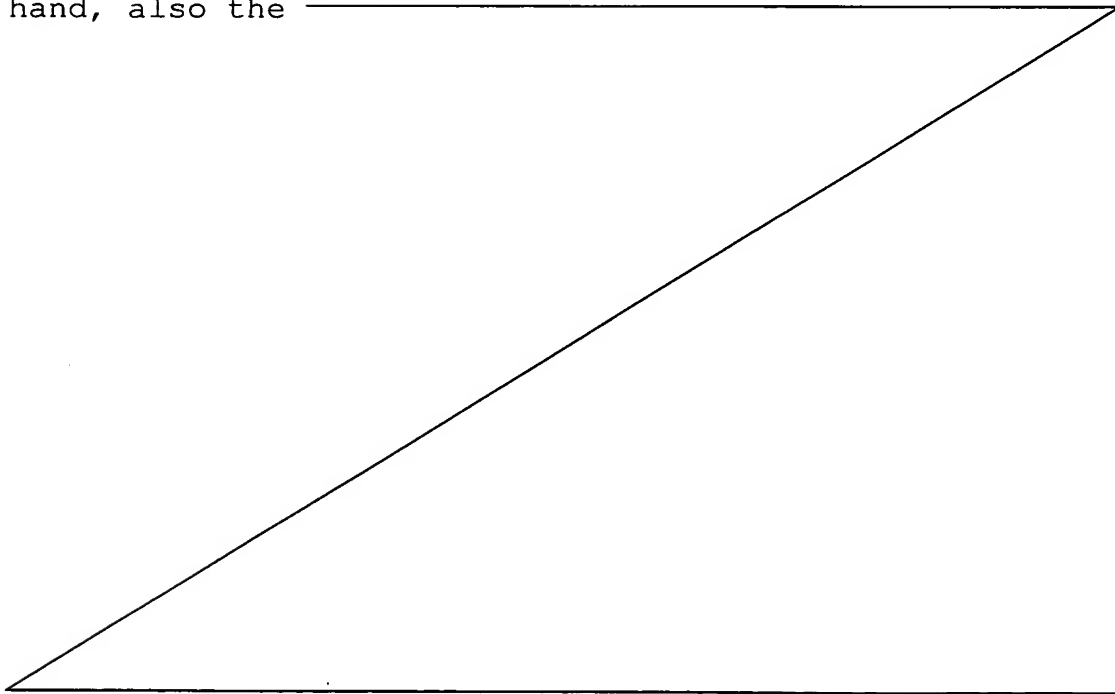
US-A-4,999,798 discloses a transient recovery-free interpolation decimator which has one adjustable delay stage and one interpolation stage per signal path.

WO 94/23492 discloses a decimation filter with cascading of at least three signal paths.

In order to recover the clock for conventional modem applications or what are referred to as MDSL applications, decimation by a non-integral factor is often necessary. In sigma-delta analog/digital conversion, comb filter arrangements are generally used for decimation, there being a multiplicity of implementation possibilities for such comb filter arrangements.

A known comb filter arrangement is illustrated in fig. 1. However, the comb filter arrangement shown there is suitable only for decimating a sequence of digital input values x_i into a sequence of digital output values y_j by an integral factor M . For this purpose, the circuit arrangement according to fig. 1 has an input-end integrator 10 of the n -th order, a following decimator stage 124 by the integral factor M and an output-end differentiator 126, also of the n -th order.

The integrator 10 of the n -th order has n stages which are connected in series, each stage comprising an input-end adder 12 to which two input signals are fed, namely a signal which is fed back via a line 16 and a signal which originates from the signal path and which is the digital input value x_i in the first stage. The output of the adder 12 is connected to a delay stage 14. In a following stage, the output of this delay stage 14 forms, on the one hand, the input signal for the adder 12 of this following stage and, on the other hand, also the



--- output of the adder 12 is connected to a delay stage 14. In a following stage, the output of this delay stage 14 forms, on the one hand, the input signal for the adder 12 of this following stage and, on the other hand, also the signal which is fed back to the assigned adder 12 via the line 16. For an integrator of the third order, for example three such stages, each with an adder 12, a delay element 14 and a feedback loop 16, are necessary.

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The output signal of such an integrator 10 of the n -th order is fed to the decimator stage 124, which filters out, for example, only every tenth incoming sampled value. The output of the decimator stage 124 is connected to the differentiator 126 which has already been mentioned and which also has a predefined number of stages connected in series, in accordance with the order of the differentiator. These stages each have in turn an adder 128, a delay stage 130 and a line 132, but, in contrast to the stages of the integrator 10, they are wired differently. Two input signals, namely on the one hand the signal on the line 132 of the signal path and the signal which is delayed and inverted with respect thereto in the delay stage 130, are in turn fed to the adder 128. The output of the adder 128 is then fed to the one input of the adder 128 of a following stage, and also to the delay stage 130 there. Three such stages connected in series are necessary in order to implement a differentiator of the third order.

Such a comb filter arrangement is suitable for decimating the sequence of digital input values x_1 by an integral factor M , for example 10.

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The invention is based on the object of developing the comb filter arrangement which is described in fig. 1 and is known, in such a way that it is possible to

decimate the sequence of digital input values x_i by a non-integral factor.

This object is achieved by means of a comb filter arrangement having the features of claim 1.

Developments of the comb filter arrangement are the subject matter of the subclaims.

According to the invention, an input-end integrator of the n -th order, whose output is fed to at least three signal paths, is accordingly provided. Each signal path has a delay stage with a delay which can be set to different values, a following decimator stage by an integral factor M , and an output-end differentiator stage for generating intermediate output values. An interpolation arrangement, at whose output the sequence of digital output values y_j which are decimated by the non-integral factor can be tapped, is connected to the output of the three signal paths.

The interpolation arrangement is constructed in such a way that it always interpolates between two intermediate output values which are present at the output end on the three signal paths and have an interval of k/f (f = sampling rate and k = delay factor). The interpolation is expediently a linear interpolation.

The differentiator stages of the individual signal paths operate according to the invention with a sampling rate which is reduced by the factor M , as a result of which the expenditure on adders and delay elements is advantageously low. In order to achieve the non-integral change in the sampling rate, the interpolation is carried out according to the invention between two intermediate output values which are delayed by the respective signal paths.

In one embodiment of the invention, the interpolation arrangement has two switch-over devices whose three inputs are each connected to an output of the three
5 differentiator stages and whose outputs are each connected to one amplifier. Furthermore, an adder stage is provided for adding the output signals of the two amplifiers.

10 A further embodiment of the invention provides a control device for switching over the switch-over devices in each case in accordance with the two intermediate output signal values to be interpolated.

15 Another embodiment of the invention provides for the interpolation arrangement to carry out a linear interpolation in accordance with

$$y_j = \alpha \cdot y_{i+1} + (1 - \alpha) \cdot y_i$$

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or

$$y_j = \alpha \cdot y_{i+k} + (1 - \alpha) \cdot y_{i+3k}$$

25 For this purpose, only two multiplication operations and one addition operation are required within the interpolation arrangement at the low sampling rate. After a predefined number of such interpolation operations, the system is switched over to
30 interpolation, as stated in the above formulae, between the two value pairs (y_i, y_{i+k}) and the value pair (y_{i+k}, y_{i+2k}) .

A very central feature of the comb filter arrangement
35 according to the present invention is the fact that only two value pairs are required for interpolation.

Because n differentiators are provided in the respective signal paths after the decimator stage in the comb filter arrangement according to the invention, the comb filter arrangement requires n steps for transient recovery so that only the $n + 1$ -th output value after the switching over in the switch-over devices can be used by the input sequence. For this reason, each differentiator chain in the signal paths must already be phased in n steps before it is connected to the output.

It is of crucial significance in the comb filter arrangement according to the invention that the interpolation always takes place between two values which are at an interval of $k \cdot T$ ($T = 1/f$, f = high sampling rate). As a result, in all cases it is possible to interpolate k times between the value pairs (y_i, y_{i+k}) without requiring a new support point. These are precisely those k steps which are required by a chain of k differentiators for the transient recovery and/or which are required in order to calculate the values of the k registers of the differentiators. The output value of the differentiator chain can then already be used in the next step.

A comb filter arrangement according to the invention can be implemented in a wide variety of ways. The third signal path can be implemented, for example, by means of a separately constructed differentiator chain corresponding to the logic for phasing in and switching over. However, it is also possible to implement just one software calculation and to correspondingly charge the registers of the differentiator chain.

The comb filter arrangement according to the invention is explained in more detail below in conjunction with an exemplary embodiment with reference to further figures, in which:

fig. 1 shows a comb filter arrangement according to the prior art,

5 fig. 2 shows a comb filter arrangement according to the present invention in a block circuit diagram, and

10 fig. 3 shows an outline of sequences of input values, intermediate output values and output values in the circuit arrangement of fig. 2 as well as the associated interpolation values.

15 In the following figures, identical reference symbols indicate identical parts with identical meaning, unless stated otherwise.

Fig. 2 shows a comb filter arrangement for decimating a sequence of digital input values x_i into a sequence of digital output values y_j by a non-integral factor $M + \alpha$, M being a positive integer, that is to say $M = 1, 2, 3, \dots$ etc., and $0 < \alpha < 1$. The arrangement has an input-end integrator 10 of the n -th order, as has been explained, for example, in conjunction with 25 fig. 1. The output of the integrator 10 is split into three signal paths 20, 30, 40. The first signal path 20 has a delay stage 22 with a downstream decimator stage 24 and a downstream differentiator 26. The decimator stage 24 decimates the sequences of data delayed in the delay stage 22. The differentiator 26 is of the n -th order. A sequence of intermediate output values y_i can be tapped at the output of the differentiator 26. The output of the differentiator 26 is connected to two input terminals e_1 , each of a switch-over device 35 62, 64.

The second signal path 30 and the third signal path 40 are of very similar construction to the first signal

path 20 and each have a delay stage 32, 42 with downstream decimator stage 34, 44 and further downstream differentiators 36 and 46. A sequence of intermediate output values y_{i+k} can be tapped at the output of the second differentiator, and a sequence of intermediate output values y_{i+2k} can be tapped at the output of the third differentiator. The output of the second differentiator 36 is connected to second input terminals e2 of the first switch-over device 62 and of the second switch-over device 64. The output of the third differentiator 46, which is of the n-th order like the first differentiator 26 and the second differentiator 36, is connected to a third input terminal e3 of the first switch-over device 62 and to a third input terminal e3 of the second switch-over device 64. The delay time of the delay stages 22, 32 and 42 can be adjusted by a control device 100 using a control signal S.

In the comb filter arrangement of fig. 2, the delay stage 22 delays by $k \cdot T$, the delay stage 32 by $2k \cdot T$ and the delay stage 42 by $3k \cdot T$ (where $T = 1/f$, f = sampling rate and k = the basic delay factor).

The two switch-over devices 62, 64 are configured in such a way that they switch the signals present at the input terminals e1, e2 or e3 to an output terminal a of the respective switch-over device 62, 64. The output terminal a of the switch-over device 62 is connected to a first amplifier 70 which is connected at the output end to an input terminal of an adder 80. The output terminal a of the switch-over device 64 is connected to the input terminal of a second amplifier 72 whose output terminal is connected to a second input terminal of the adder 80. At the output of the adder 80 it is possible to tap a sequence of output values y_j which is decimated by a non-integral factor with respect to the

sequence of input data x_y . The two switch-over devices 62, 64, the two amplifiers 70, 72 and the adder 80 form an interpolation arrangement 60.

- 5 The non-integral factor is, for example, $M + \alpha$, M being a positive integer, that is to say 1, 2, 3 etc., and α = gain factor of the first amplifier 70. The gain factor of the second amplifier 72 which is selected is then $1 - \alpha$.

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As is also apparent from fig. 2, the control device 100 can control the switching over of the two switch-over devices 62 and 64 and the gain factor of the two amplifiers 70 and 72.

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The method of operation of the circuit arrangement illustrated in fig. 2 is explained in conjunction with the sequences of input values and output values illustrated in fig. 3.

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A sequence of digital input values x_1 is illustrated by way of example at the top of fig. 3. The individual input values x_1 have an interval of T from one another.

- 25 In the diagram below the latter in fig. 3, a sequence of digital values is illustrated. It is assumed that the integral factor $M = 6$. The associated values decimated from the sequence of input values x_1 are determined by the interval $M \cdot T$. Between these values
30 there are further signal values which are predefined by the delay $k \cdot T$ or $2k \cdot T$.

- The individual signal values resulting from this are designated, in accordance with the convention, as
35 intermediate output values y_i , y_{i+k} and y_{i+2k} in accordance with the delay or lack of delay thereof. The interpolation times to be interpolated are indicated in fig. 3 by arrows. As is apparent, the interpolation

--- times are always between two intermediate output values, namely between y_i and y_{i+k} on the one hand and between y_{i+k} and y_{i+2k} on the other.

- 5 The interpolation arrangement 60 illustrated in fig. 2, comprises the two switch-over devices 62 and 64, the two amplifiers 70 and 72 and the adder 80. The control device 100 switches the two switch-over devices 62 and 64 over and selects the gain factors of the amplifiers
10 70 and 72 in such a way that a linear interpolation is implemented.

The control device 100 ensures that in principle linear interpolation is carried out between the values y_i and
15 y_{i+k} according to the formula

$$y_1 = \alpha \cdot y_{i+1} + (1 - \alpha) \cdot y_i.$$

- For this purpose, only two multiplication operations
20 and one addition operation at the low sampling rate are required. However, after k such interpolation procedures, instead of the value pair y_i, y_{i+k} the value pair y_{i+k}, y_{i+2k} is required for interpolation.

- 25 Because the second part of the comb filter arrangement illustrated in fig. 2 composed of the respective n differentiator stages 26, 36 and 46 connected in series requires n steps for its transient recovery, the control device 100 must make allowance for the fact
30 that only the $(n + 1)$ -th output value is used after the switching over of the input sequence. For this reason, each differentiator chain 13 must be phased in n steps before it is switched to the output.